A Pump Control Index For Reducing Suction and Backflow Effect Caused by the Portable Centrifugal Blood Pump

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Abstract-**In this experiment, the Taita No. 1 centrifugal blood pump was implanted on the calf. The blood pump was driven by constant voltage with the open-loop control method. The pump inflow flow and pump outflow pressure were recorded and analyzed synchronously. According to the status of aortic valve and mitral valve, the cardiac cycle was divided into four stages. The flow in each stage was calculated and an optimal pump control index was obtained. The index suggests an optimal applied voltage of pump for reducing suction and backflow effect.**

***Keywords*- blood pump control, suction, backflow, LVAD**

I. INTRODUCTION

The left ventricular-assist device (LVAD) is designed to aid the pumping function of the natural heart without replacing it. The rotary blood pump operating in continuous flow mode was the new generation LVAD [1]. The rotary pump has some advantages: small size, high efficiency and simplicity of implantation. However, the rotary blood pump is valve-less so that the backflow effect can't be avoided. The backflow effect occurs at low pump speed and the suction effect occurs at high pump speed. Both of them are deleterious on the host physiological system and highly related to pump speed. For this reason, the pump speed control is very important. There were several methods to detect and minimize suction and backflow effect using motor current waveform analysis [2][3]. In this paper, the purpose was to obtain a control index that could be applied on optimal pump speed control and reduced suction and backflow effect.

II. METHODOLOGY

The centrifugal Taita No. 1 ventricular-assist device (T-LVAD) was implanted on a calf, which weighted around 80 kg. This experiment setup was shown in Fig. 1, a 3/8 inches polyurethane tube with polytetrafluoroethylene cuff sutured to the descending aorta as the outflow tube of T-LVAD. A 32-French polyurethrane tube was inserted into the left ventricle via the left auricle through the mitral valve. The Hewlett-Packard bedside monitor was used to detect the blood pressure waveform of the outflow of T-LVAD. The ultrasonic flow probe (T206 Transonic System Inc., Ithaca, NY, USA) was attached to the inflow of T-LVAD and recorded the pump flow. The blood pump was electromagnetic coupling driven by a DC motor, which was controlled by constant voltage from 10V to 18V with open-loop control. All of the ECG, pump outflow pressure, pump inflow flow and pump speed were converted to electrical signal synchronously. Via the data acquisition card (NI DAQ card, type 6035E), the signals were sampled at 250 Hz sampling rate with 16 bits resolution and transmitted to the computer.

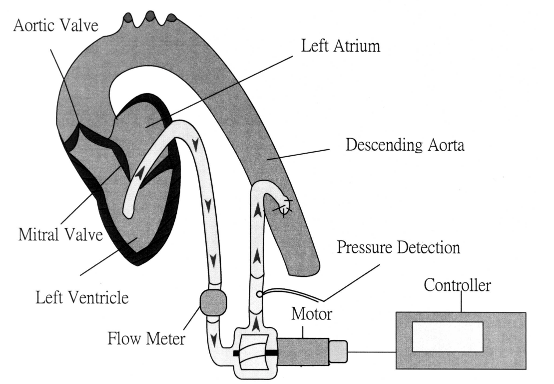

Fig. 1. The experimental setup diagram. The inflow tube of T-LVAD was inserted into the left ventricle via the left atrium crosses mitral valve and outflow of T-LVAD is end-to-side anatomist on the descending aorta. The flow and pressure was monitored separately in pump inflow and pump outflow site.

The cardiac cycle was divided into four stages according to the status of aortic valve and mitral valve that were defined on the pressure waveform shown in Fig. 2. In each stage, mean pump flow was calculated by the following equation.

$$Q_i = \frac{1}{t_{i+1} - t_i} \int_{t_i}^{t_{i+1}} Q(t)dt \qquad (1)$$

Where i is from 1 to 4, t1 is the time of mitral valve close (MVC), t2 is the time of aortic valve open (AVO), t3 is the time of aortic valve close (AVC), t4 is the time of mitral valve open (MVO) and Qi is the mean pump flow of stage i.

All animals involved in this study received humane care in compliance with guiding principles in the care and use of animals approved by the Institutional Laboratory Animal Committee of National Taiwan University.

III. RESULTS

A constant voltage from 10V to 18V was applied on this blood pump and the pump outflow pressure was increased with the applied voltage of motor (Vm). The Vm and pump inflow flow, pump speed, pump current were highly linear related. With the Vm varying, the pump inflow flow varied from –0.24 to 4.38 L/min and the pump speed varied from 2446 to 4228 RPM.

According to (1), the mean pump flow in each stage was calculated and averaged for 75 cardiac cycles. The result showed that Q1>Q4>Q2>Q3. Here we defined a flow index Q12/Q34, which equals (Q1+Q2)/(Q3+Q4), the relationship between Vm and the flow index was shown in Fig. 3.

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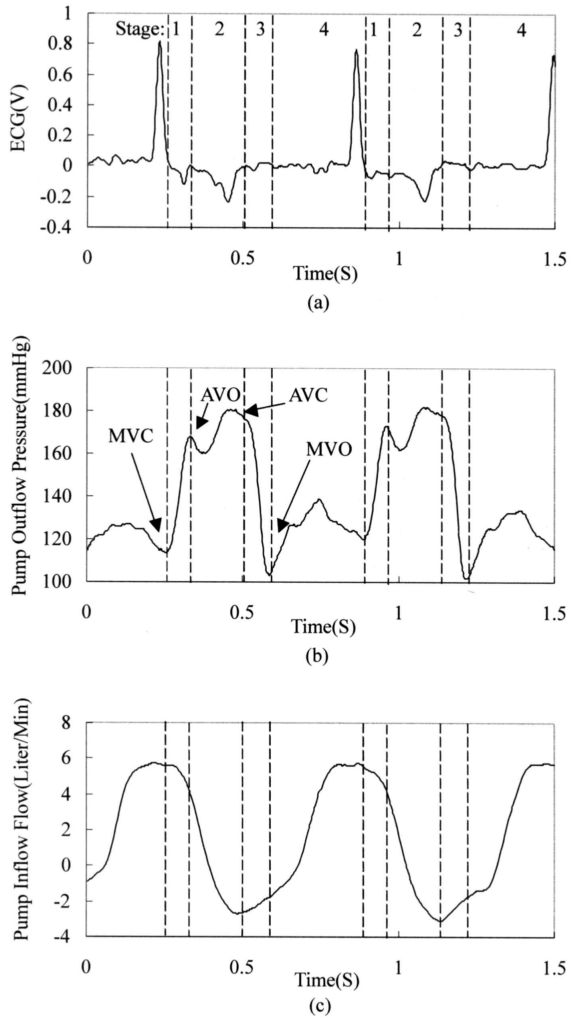

Fig. 2. (a) ECG waveform. (b) Pump outflow pressure waveform. (c) Pump inflow flow waveform. The MVC, AVO, AVC and AVO were defined as above. The stage1 is between MVC and AVO, stage 2 is between AVO and AVC, stage 3 is between AVC and MVO, and stage 4 is between MVO and next MVC. The waveforms shown in above was measured in Vm = 14V.

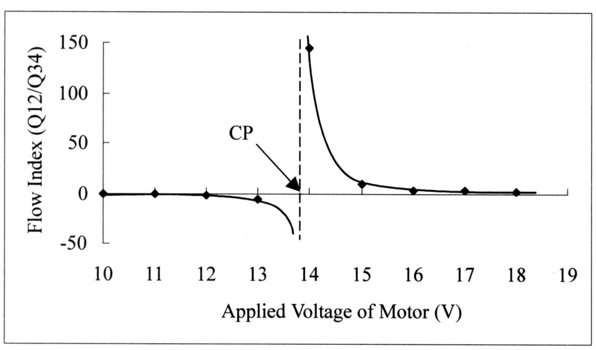

Fig. 3. The relationship between applied voltage of motor and flow index Q12/Q34. The turning point was around Vm = 13.8V (CP). The serious backflow effect occurs at Vm lower than CP and the suction effect would arise at Vm higher than CP.

The flow index approached to infinity at the control voltage about 13.8V, which we defined as the critical point (CP). The Vm values lower than the CP would induce serious backflow effect while Vm values higher than the CP would cause suction effect. Hence, the index Q12/Q34 may be a good indictor for optimal motor control.

IV. DISCUSSION

Considering the flow index variation at CP, we suggested the isovolumetric ventricular relaxation phase, stage 3, to be the critical stage in cardiac cycle. In this phase, the blood volume in ventricle was the least and pressure was the lowest, at lower Vm serious backflow effect could occur. Higher Vm would cause suction effect and hemolysis, which is dangerous especially in this phase. Consequently, the Vm value seems to be satisfied at CP, and the flow index Q12/Q34 could be a good control index of the LVAD.

When Vm was applied at 13.8V, the pump speed was around 3200 RPM, pump flow was 1.37 L/min and pump outflow pressure was about 135 mmHg. The physiological condition seems ideal under this voltage control. The value had been used on chronic animal experiment and also got good results.

V. CONCLUSION

The T-LVAD was implanted on a calf, the ECG, pump inflow flow and pump outflow pressure were recorded and processed. A pump control index for reducing suction and backflow caused by the centrifugal blood pump was obtained.

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